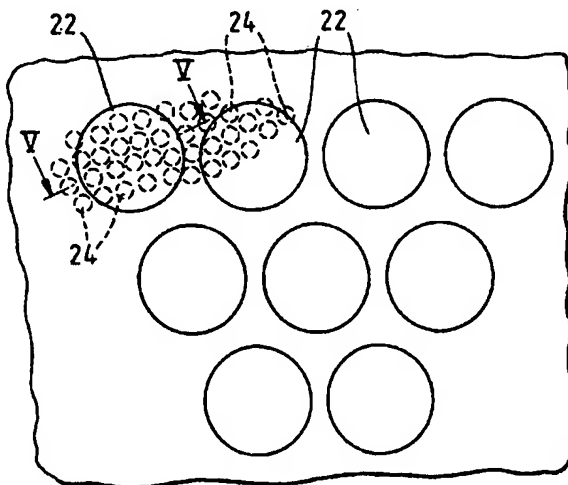




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(54) Title: IMPROVEMENTS IN OR RELATING TO MICROLENS SCREENS AND THE LIKE



(57) Abstract

Various combinations of different optical features in a microlens screen are disclosed. In one arrangement, a screen is provided for depixelating purposes, comprising an array of transparent rectangular portions (14) in a light diffusing field (20) formed by minute closely packed microlenses of the graded refractive index type. In another arrangement, a screen formed with an array of integral graded refractive index lenses has surface refractive index lenses additionally provided by part-spherical embossments on a surface of the screen, the embossments being of one or more orders of magnitude greater in diameter than the graded refractive index lenses. There are also disclosed techniques for preventing light transmission through a microlens screen except through the microlenses, the use of microlens screens to improve the performance of solar panels and microlens screens conforming to a part-spherical surface.

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Title: "IMPROVEMENTS IN OR RELATING TO MICROLENS SCREENS AND THE LIKE"

THIS INVENTION relates to light diffusing and depixelating screens or layers incorporating graded refractive index (GRIN) microlenses or other optical features. Screens of this type, made from photopolymerised material are disclosed, for example, in European Patent Specification No. 0294122, International (WO) Published Specifications Nos. WO91/18304 and WO92/1605 and in co-pending International Patent Application PCT/GB94/01281 to which reference should be had.

European Patent No. 0294111 discloses a microlens screen comprising a sheet of transparent material formed with an array of integral microlenses which are spaced apart from one another in the plane of the sheet with each microlens having an optical axis extending through the sheet material from one major face thereof to another, for example extending normal to the plane of the sheet material or inclined relatively slightly to a normal to such plane.

In the microlens screen disclosed in European Patent No. 0294122 the transparent material is a variable refractive index polymer and the individual lenses, forming said array of microlenses, are graded refractive index (GRIN) lenses or which owe at least a substantial part of their optical power to graded refractive index effects in the polymer.

The present invention relates to light diffusing screens having graded refractive index features which are not, strictly speaking, lens-like in character, as well as to screens having graded refractive index microlenses.

According to one aspect of the invention there is provided a microlens screen which is provided, on at least one surface thereof, with an opaque coating extending over the regions between adjoining microlenses in the array but not occluding the microlenses themselves.

Preferably the opaque layer is black.

European Patent No. 0294122 describes a method of making a graded refractive index microlens screen in which a photopolymerisable monomer, for example an acrylamide monomer, provided in the form of a sheet or layer of viscous fluid or tacky gel, is exposed selectively at each of a plurality of spots (corresponding to the eventual microlenses) to ultraviolet light to cause polymerisation selectively in the spots illuminated. Subsequently, after polymerisation in the region of the spots so illuminated, the material is subjected to a blanketing exposure to ultraviolet light to cure the remainder of the material unexposed during the initial, selective exposure. The material may be heated before or after the selective exposure.

In a preferred embodiment of the above-noted aspect of the present invention, in which the microlens screen comprises a sheet of photopolymer material substantially as disclosed in European Patent No. 0294122, advantage is taken of the fact that, at a time after the selective exposure and before the blanketing exposure, the unpolymerized material (monomer) is significantly tacky, whereas the photopolymerized material, which forms the individual microlenses, is substantially dry and non-tacky, by applying to one surface of the material, after it has been selectively exposed in the regions where microlenses or analogous features are desired to be formed but before

the subsequent blanketing exposure, a layer of a black opaque material, such as Chromalin, which adheres to the tacky regions but not the dry polymerised regions defining the microlenses. Subsequently the Chromalin material is removed from the non-adhesive regions. The same technique may be applied to certain other photopolymers. For example, the photopolymer used may be that supplied by Du Pont under the Registered Trade Mark OMNIDEX and having the type designation HRF150 or HRF600. The monomer in the HRF series photopolymers is fluorescent N-vinyl-carbazole (NVC) dispersed in a plasticized polyvinyl acetate (PVAC), cellulose acetate butyrate (CAB) or polyvinyl butyrate (PVB) as the polymeric binder. The material may be initiated either by photoinitiators or by a photosensitizing dye/initiator combination.

The OMNIDEX materials are available in sheet form, comprising a layer of the monomer on a polyester film base (MYLAR) the layer being entirely covered with a polyester (MYLAR) film.

Chromalin comprises a layer of extremely finely divided pigment particles (black pigment in the present context) weakly bonded to a supporting film. In the preferred embodiment of the invention in this aspect, after the photopolymerisable material has been exposed in the regions where the microlenses are desired to be formed but before the subsequent blanketing exposure, said supporting film is applied to the photopolymerisable material, with the pigment layer adjoining the photopolymerisable material and is brought into intimate contact with the latter, e.g. by rolling. The supporting film is subsequently peeled off, taking with it the pigment particles which were in contact with the non-tacky polymerised regions, but leaving the pigment adhered to the tacky regions. The

photopolymerisable material may then be subjected to a blanketing exposure to polymerising light.

The technique described above is of particular utility in relation to microlens arrays which, for one reason or another, are required to be strictly regular, since in such cases a substantial percentage of the screen is necessarily occupied by interstices between adjacent microlenses, whereas if a regular array is not required, then it may be possible to adopt arrangements in which interstices between larger adjoining microlenses are at least partially occupied by smaller microlenses, substantially reducing the percentage of the screen through which non-refractive light transmission is possible.

In another variant, the aperture mask is formed from black acrylic sheet material formed with a plurality of circular apertures in a regular array corresponding to the desired microlens array. To this acrylic sheet is applied a layer of the photopolymerisable monomer material. The photopolymerisable monomer may be stocked in sheet form comprising a layer of the photopolymerisable material on a backing of flexible Mylar sheet, the layer of photopolymer being in turn covered by a relatively thin protective release sheet. Using the photopolymerisable material in this form, therefore, the release sheet is first stripped off, the exposed (and tacky) surface of the monomer applied to the acrylic sheet and pressed thereagainst to adhere thereto and thereafter the Mylar backing sheet is stripped from the photopolymerisable layer. The photopolymerisable material is then exposed to UV light through the black acrylic "mask" to produce the microlenses by selective photopolymerisation of the material in contact with the mask. The subsequent blanketing exposure to UV light is, of course, from the side opposite the acrylic sheet.

The black acrylic mask, which remains in situ with the photopolymer, serves to prevent light from passing through the screen without passing through the lenses, i.e. from passing through the interstices between lenses. This form of microlens screen, like the form in which Chromalin pigment between adjacent microlenses performs the same function as said black acrylic mask, is well suited to use in a close viewing arrangement for pixelated LCD screens, for example. Thus, in one arrangement, care is taken, by appropriate control of parameters, to ensure that each microlens is as free from aberration as is practicable and that each lens in the array is of the same diameter and focal length and that the array is regular to ensure a good packing ratio (i.e. ratio of area made up by microlenses to area made up by interstices between microlenses). The microlens screen is so arranged in relation to the LCD screen that the spacing between the LCD screen and the median plane of the microlens screen is substantially equal to the focal length of the microlenses, so that the light emerging from each microlens is substantially in the form of a respective parallel beam, so that to an observer the image of the LCD screen is perceived to be at infinity.

Whilst, in many applications of microlens screens, the image-forming quality of the individual microlenses is of little relevance, in some applications it is desirable for each lens to have a well-defined focus with consequently good image-forming properties. For such applications it is desirable that each microlens acts substantially as a conventional spherical lens. One way of achieving this desired result is to utilize, instead of an aperture mask as disclosed in European Patent No. 0294122 in which each "aperture" is characterised by an abrupt transition from transparency to opacity at its edges, a mask in which each "aperture" has its "edge" regions formed

as a neutral filter of precisely determined variation in density from the edge of the "aperture" towards the centre thereof, thereby controlling more precisely the variation in U.V. illumination over the region of the intended microlens and thus controlling more precisely the refractive index changes across the lens. (As disclosed in European Patent No. 0294122, diffraction at the edge of each aperture already contributes some of the desired light intensity variation, whilst the tendency of polymerisation to "spread" from an illuminated area into a non-illuminated area, for example, produces some variation in the degree of polymerisation, and hence in refractive index variation independently of variation in polymerising U.V. exposure). Of course, the precise mode of radial variation of neutral filter density in each aperture should be determined having regard to the above-noted other effects which contribute to refractive index variation across the lens.

Where the photopolymerisable material has a surface unconfined by, for example, an overlying plastics film, during polymerisation, such polymerisation results in a relief pattern on such surface which, in the case where the GRIN lenses are converging lenses, provides such lenses with convex end surfaces. Heating of the material during polymerisation tends to "spread" such profiling in such a way as to render more accurately spherical such end surfaces.

In accordance with another aspect of the invention there is provided a microlens screen comprising a sheet of photopolymer incorporating an array of graded refractive index microlenses, said sheet having, additionally, at least one major surface thereof embossed or otherwise surface-contoured so as to afford, in use, a lens action due to refraction at the surface of each such embossment,

independently of and additional to the lens action of each graded refractive index lens.

Whilst, in some embodiments there may be, for example, a respective part-spherical embossment for each graded refractive index lens in the photopolymer material and in optical alignment with its graded refractive index lens, so that the graded refractive index lens and its respective part-spherical lens form, in effect, a multi-element lens, in preferred embodiments of the invention, there is no strict one-to-one relation between the graded refractive index lenses and the embossments and, indeed, in the preferred embodiment of the present invention the individual part-spherical (for example) or quasi part-spherical embossments may have diameters one or several orders of magnitude greater than the individual graded refractive index lenses.

The invention, according to this aspect, makes it possible, in effect, to separate the light mixing and diffusion effect, primarily carried out by the array of graded refractive index lenses, from larger scale distribution of light from the screen in directions at angles to the normal to the screen (assuming the light in question to be incident normally onto the screen). Thus where, for example, the diffusing screen is intended to perform a depixelating function in relation to a colour LCD display or C.R.T., the GRIN microlenses serve to mix the light from the Red, Green and Blue pixels for each picture element, allowing the perception of each picture element as being of the intended colour rather than as comprising three distinct areas or pixels of red, green and blue respectively, whilst the embossed lenses serve to direct desired proportions of the thus mixed light to various desired angles off-axis to ensure, for example, that th

screen appears to the eye to be uniformly illuminated across its width and height, without any "hot spot" effect and to ensure that satisfactory off-axis viewing of the screen is possible. Thus the GRIN lenses and the embossments can, with fewer restraints, be configured to suit their respective functions.

Whilst, for convenience, the surface configuration or contouring of the screen has been described above as being provided by embossing, it will be appreciated that a corresponding effect may be provided by, for example, applying the photopolymerisable material in a flowable or liquid state to a mould surface of complementary configuration, without departing from the invention.

Furthermore, instead of forming the embossments or surface lenses directly on the photopolymer material, such embossments or surface lenses may be formed on a separately provided transparent sheet which is subsequently bonded to the photopolymer sheet.

According to another aspect of the invention there is provided a method of improving the performance of photo-electric sensors or solar cells of the type comprising a mono-crystalline plate of semi-conductor material, such as silicon, doped to form a P-N junction parallel with and close to the surface of the plate which is exposed to light, which method comprises providing over the exposed surface of such semiconductor plate a microlens screen as herein defined, each microlens being arranged to focus the light falling thereon onto a respective spot on such surface. Thus, the light falling on the sensor or solar cell is focused onto a plurality of discrete spots on the surface of the semiconductor material. It has been found that such an arrangement, for a given average illumination

of the exposed semiconductor surface, provides a higher electrical output from the device than an arrangement where the same average illumination is provided uniformly across said surface. By utilising this technique, it is possible to obtain a higher signal to noise ratio for such a semiconductor device when used as a detector of illumination or sensor than in known arrangements where such device is illuminated uniformly. Likewise, where such semiconductor devices are used, for example, in an extended array as a generator of electricity, for example as a so-called solar panel, it is possible, using the technique described, to provide a higher electrical output from such a panel. By way of example, a solar panel may comprise a plurality of individual solar cells of the type referred to covered by a single microlens screen which thus, in addition to affording the focusing effect referred to above, also serves to protect the individual cells from physical damage, ingress of water, etc. A corresponding technique may be used in relation to amorphous semiconductor sensors or solar cells.

There are applications in which it is necessary or desirable to deal with curved image surfaces, for example in conjunction with optical systems affording curved image surfaces, for example part-spherical image surfaces, and where, nevertheless, the diffusion properties of a microlens screen, as herein defined, would be beneficial. In accordance with another variant of the invention, a curved microlens screen, or indeed a microlens screen conforming to any desired surface configuration, can be formed by providing a former affording a curved surface of the desired shape, or a surface whatever other configuration is required, applying a layer of photopolymerisable material to said surface to conform therewith and exposing the photopolymerisable material to

ultra-violet light through a correspondingly configured opaque mask having light-transmitting apertures of predetermined size and shape and in a predetermined arrangement or array to form a microlens diffusing or other array lying substantially in the desired spherically curved (or other configured as desired) surface. The aperture mask may itself be formed by depositing on said former surface, or on a supporting film applied to said surface, a layer of an opaque etchable material, such as metallic chrome, depositing a photoresist on said layer of etchable material, exposing the photoresist to an appropriate light pattern, removing the unexposed photoresist, and etching the etchable material in the regions so exposed, to provide a mask conforming to the spherical or other desired surface and having the desired arrangement of light-transmitting apertures therethrough. Of course, the exposure of the photoresist in the above process may itself be made through a part-spherical mask (or mask of other desired configuration) of silver halide photographic emulsion on a conforming light-transmitting substrate (for example formed by applying a layer of a curable transparent resin to the mould surface or to an identical mould surface and exposing the photographic material to spots of light, spot by spot, at the desired locations, and then developing the photographic medium.

Another embodiment of the invention is of particular utility in relation to the depixelation of LCD visual display screens, particularly LCD display screens of small size intended to be viewed under magnification, for example, in the viewing device which is the subject of International Patent Application PCT/GB92/00396 published as WO92/16075. Such depixelation, whilst particularly desirable in relation to LCD screens in view of the relatively large dimensions of the pixels having regard to

the typically small overall size of such screens, may also be applied, with advantage, to CRT displays, particularly colour CRT displays where the colour picture is made up of discrete red, green and blue dots which are perceptible, at least at close range, in the same way as the pixels of an LCD screen. Accordingly, microlens screens as described in the prior patent and applications referred to above and, where appropriate, as described herein, may usefully be used with CRT displays, for example, with the microlens screen being applied to the face of the CRT tube, or being incorporated in the wall of the tube which affords the display screen during manufacture for example so as to be immediately adjacent the CRT phosphor or closer thereto than would be possible if the microlens screen were applied after the tube had been sealed and evacuated, bearing in mind the thickness of the screen wall of the finished tube necessary to provide the required strength. Even in relation to monochrome CRT displays, the use of such a microlens screen may be advantageous in ensuring that the light from the display is efficiently channelled in the direction in which it is most required, i.e. towards the presumed viewer, thereby enhancing perceived brightness and contrast.

Preferred embodiments of the invention, in some of the above-noted aspects, are described below, by way of example, with reference to the accompanying drawings, in which:-

FIGURE 1 is a diagrammatic fragmentary view, to an enlarged scale, of a pixelated LCD screen,

FIGURE 2 is a diagrammatic fragmentary view, to a similarly enlarged scale, of a depixelating screen embodying the invention,

FIGURE 3 is a corresponding fragmentary view of a mask which may be used in production of the depixelating screen of Figure 2,

FIGURE 4 is a diagrammatic fragmentary view to an enlarged scale, of a microlens screen embodying the invention in another of its aspects, and

FIGURE 5 is a diagrammatic sectional view along the line V-V of Figure 4.

Referring to the drawings, Figure 1 illustrates a fragment of an LCD screen, which consists, in manner known per se, of an array of pixels 16, (here shown as square or rectangular) which form the picture elements and transmit light or not according to electrical signals applied in a manner known per se to associated conductors. The reference numeral 12 in Figure 1 represents a region defined by the interstices between adjacent pixels 16. These interstices are necessarily of appreciable width (although their width is exaggerated in Figure 1), and are necessary to preserve electrical separation between the transparent electrically conductive elements which define the pixels and to accommodate transparent electrically conductive strips extending to the various pixels. These regions 12 thus detract from picture information rather than contributing to it. The LCD display is generally arranged so that the regions 12 appear black to the viewer since this makes them less obtrusive, but they still represent a visually undesirable feature of the display particularly if the display is to be viewed under magnification. In accordance with the present invention and referring to Figure 2, it has been found that the black interstitial region 12 can be rendered less visible or invisible by arranging in front of the LCD screen, (but

behind any optical system used for magnification of the LCD screen image) a light-diffusing screen comprising an array of transparent "windows" 14 with the screen material having light-diffusing characteristics in the interstices 20 between windows 14. There is one window 14 for each pixel 16 of the display and each window 14 is in alignment with its respective pixel 16. The windows 14 are also of substantially the same shape as their respective pixels and are thus of generally square or rectangular configuration in Figure 2. However, as perceived by the viewer, the diffusion region 20 encroaches to a significant extent over the edges of the pixels 16, as illustrated in broken lines in Figure 2, so that the edges of the pixels 16 as well as the regions 12 of the LCD screen are masked by the diffusing regions 20. The diffusion regions 20 tend to spread the light from the pixels into the interstices between the pixels, as viewed, thereby minimising or even eliminating the perception of the interstitial regions 12. Preferably the light-diffusing screen is formed of a photopolymer graded refractive index material such as referred to above and is made in the following fashion. A layer of the photopolymerisable material is exposed to ultra-violet light through a mask of the form illustrated schematically and fragmentarily in Figure 3, comprising an array of rectangular opaque regions 18, corresponding to the desired windows 14 and, in the interstices between opaque areas 18, a dense array of light-transmitting apertures in an opaque background, or vice versa, and which array is represented at 19 by the cross-hatching in Figure 3. Such a mask may be formed photographically by exposing a layer of silver halide photographic medium to laser light through a ground glass or fibre optic screen to produce a "speckling" exposure of the photographic material in the manner described in co-pending International Patent Application PCT/GB94/01281. The photographic medium is

then exposed to a pattern of fully illuminated rectangles (corresponding to the regions 18 in Figure 3), in the desired array and the photographic medium developed and subjected to a photographic reversal process, known per se, (so that regions exposed to light are transparent in the resulting "transparency" whereas portions not exposed are opaque). The resulting transparency is then used to produce, by known photo-etching techniques, a "negative" of the transparency, a metallic chromium mask through which the photopolymeric material is exposed. The reversal processing of the photographic material results in a desirable sharp contrast and definition in the pattern.

The square or rectangular regions may be exposed on the photographic material using an appropriate imaging system. By way of example, the square or rectangular regions may be exposed one at a time, or a group or sub-array at a time, using an imaging laser technique such as an E-beam imaging technique, with the laser being indexed with respect to the photographic medium, or vice versa, at each exposure step.

It may be useful to arrange that the diffusing effect of the region 20 in the diffusing screen diminishes gradually towards the middle of the respective window 14 and this may be achieved by providing the rectangular opaque regions 18 in the mask with edges which are substantially irregular on a microscopic scale rather than relatively abrupt. This may be achieved, for example, by having such edge regions fractally composed, by printing such edge regions, or those of the precursor photographic material, by printing of an E-beam written micromask, produced by E-beam lithography, onto the photographic medium at successive locations thereon.

It has been found that with an arrangement in which a depixelating microlens screen as described above with reference to Figures 1 to 3 of the drawings is superimposed upon a pixelated LCD screen, with each "window" corresponding with a respective pixel, disturbing Moiré effects may occur in certain parts of the picture area viewed or over the screen as viewed from certain viewing angles. It has been found that these effects, or their noticeability, can be much reduced by a controlled randomising of the arrangement of the transparent "windows" relative to the array of LCD pixels. In the preferred form of the invention, taking, for each "window" a nominal centre position for the centre of the "window", corresponding substantially with the position at the centre of the respective LCD pixel, each "window" is given a small displacement from that central position which is random with regard to direction in the plane of the microlens screen. The magnitude of such small displacement may also be randomly determined from window to window. If desired, such displacement may be preferentially arranged in one direction, for example horizontally, for the frequent instances where the eyes of different viewers may be at generally the same viewing level but are likely to be at a variety of different angles in a horizontal plane with respect to the screen and LCD display.

The randomisation of the "window" locations may be produced in any convenient way, and is preferably incorporated in the mask through which the photopolymerisable substance is exposed. Thus, for example, in one method, during the exposure of the master "negative" for the mask, as described above, in which the photographic medium is indexed stepwise mechanically, e.g. under computer control, in two mutually perpendicular directions in its plane and at each indexing step, using an

imaging laser, the image of the respective "window" is projected onto the respective small area of the photographic medium where the respective "window" is to be formed. With such an arrangement, in order to obtain the desired randomisation, the laser beam may be directed onto the photosensitive material by way of a mirror so mounted as to permit limited angular movement, the mirror having associated therewith deflecting means for imparting small random angular movements to the mirror to produce corresponding small deflections of the projected image onto the photosensitive material from the respective "normal" position. The deflecting means may comprise, for example, a piezo electric device or a galvo motor associated with the mirror and supplied by appropriate electric signals, for example produced by the computer controlling the indexing movement of the photographic or photosensitive plate, in accordance with random or pseudo-random numbers generated by the computer.

Referring to Figures 4 and 5, Figure 4 represents, schematically, a view to an enlarged scale, of a microlens screen comprising a sheet of light transmitting photopolymer material, which has an array of part-spherical surface embossments 22 each of which forms a respective surface-refractive converging lens (in the arrangement shown where the embossments 22 are convex). The photopolymer sheet also incorporates an array of integral graded refractive index lenses, indicated in broken lines at 24, the lenses 24, like the lenses 22, being spaced from each other in the plane of the sheet, with each microlens 24 having a respective optical axis extending through the sheet material from one major surface thereof to the other. It will be noted that the individual embossments or surface refractive lenses 22 are of substantially greater diameter than the individual graded refractive index lenses 24.

In general, the individual part-spherical or quasi part-spherical embossments 22 may have diameters one or several orders of magnitude greater than the individual graded refractive index lenses 24.

For the sake of clarity, the spacing between adjacent graded refractive index lenses 24 has been greatly exaggerated in Figure 5.

The arrangement described with reference to Figures 4 and 5 has various uses. When used as a depixelating screen, for example, this arrangement makes it possible, in effect, to separate the light mixing and diffusion effect, primarily carried out by the array of graded refractive index lenses, from larger scale distribution of light from the screen in directions at angles to the normal to the screen (assuming the light in question to be incident normally onto the screen). Thus where, for example, the diffusing screen is intended to perform a depixelating function in relation to a colour LCD display or C.R.T., the GRIN microlenses serve to mix the light from the Red, Green and Blue pixels for each picture element, allowing the perception of each picture element as being of the intended colour rather than as comprising three distinct areas or pixels of red, green and blue respectively, whilst the embossed lenses serve to direct desired proportions of the thus mixed light to various desired angles off-axis to ensure, for example, that the screen appears to the eye to be uniformly illuminated across its width and height, without any "hot spot" effect and to ensure that satisfactory off-axis viewing of the screen is possible. Thus the GRIN lenses and the embossments can, with fewer restraints, be configured to suit their respective functions.

Whilst, for convenience, the surface configuration or contouring of the screen has been described above as being provided by embossing, it will be appreciated that a corresponding effect may be provided by, for example, applying the photopolymerisable material in a flowable or liquid state to a mould surface of complementary configuration, without departing from the invention.

Furthermore, instead of forming the embossments or surface lenses directly on the photopolymer material, such embossments or surface lenses may be formed on a separately provided transparent sheet which is subsequently bonded to the photopolymer sheet.

Furthermore, it will be appreciated that concave surface embossments or the equivalent may be provided instead of convex and that the graded refractive index lenses may likewise be converging lenses or diverging lenses.

The arrangement described with reference to the drawings have in common the novel principle of incorporating in a single light-transmitting screen, light controlling or modifying features of two sorts. Thus in the arrangement of Figures 1 to 3, light diffusing areas and areas which allow light to pass substantially without modification are combined, being disposed at different locations in the plane of the screen, whilst in the arrangement of Figures 4 and 5, surface refractive lenses and graded refractive index lenses are superimposed.

Many variations on this theme are possible. Thus, considering the arrangement of Figures 1 to 3, in some applications it may be desired to utilise a screen in which an array of light diffusing areas is disposed in a clear,

transparent field, rather than vice versa as in Figures 1 to 3. Alternatively, in variants of either of the last-noted arrangements, the areas which are clear and transparent in the above-noted arrangements may be opaque, or may be tinted or may form a neutral density filter or filters, or may be polarising. Furthermore, the areas described above as polarising may instead be occupied by microlenses of different diameter or power, or optical features (such as "speckle" features) of different mean diameter or power, from the microlenses or other features in the remaining areas and so on.

Whilst, in many applications of microlens screens, the image-forming quality of the individual microlenses is of little relevance, in some applications it is desirable for each lens to have a well-defined focus with consequently good image-forming properties. For such applications it is desirable that each microlens acts substantially as a conventional spherical lens. One way of achieving this desired result is to utilize, instead of an aperture mask as disclosed in European Patent No. 0294122 in which each "aperture" is characterised by an abrupt transition from transparency to opacity at its edges, to a mask in which each "aperture" has its "edge" regions formed as a neutral filter of precisely determined variation in density from the edge of the "aperture" towards the centre thereof, thereby controlling more precisely the variation in U.V. illumination over the region of the intended microlens and thus controlling more precisely the refractive index changes across the lens. (As disclosed in European Patent No. 0294122, diffraction at the edge of each aperture already contributes some of the desired light intensity variation, whilst the tendency of polymerisation to "spread" from an illuminated area into a non-illuminated area, for example, produces some variation in the degree of

polymerisation, and hence in refractive index variation independently of variation in polymerising U.V. exposure). Of course, the precise mode of radial variation of neutral filter density in each aperture should be determined having regard to the above-noted other effects which contribute to refractive index variation across the lens.

Where the photopolymerisable material has a surface unconfined by, for example, an overlying plastics film, during polymerisation, such polymerisation results in a relief pattern on such surface which, in the case where the GRIN lenses are converging lenses, provides such lenses with convex end surfaces. Heating of the material during polymerisation tends to "spread" such profiling in such a way as to render more accurately spherical such end surfaces.

CLAIMS

1. A product comprising a sheet or layer of a photopolymer having in combination, first optical features and second, different optical features, at least said first optical features comprising localised regions of graded refractive index variation and/or localised contour variations, which have been produced by exposure of the corresponding monomer to a polymerising light pattern.
2. A sheet product, for example for use as a light diffusion screen, comprising a sheet or layer of a photopolymer having in accordance with a predetermined pattern, first and second areas of different light transmitting, modifying or scattering characteristics, said first areas having distributed thereover a plurality of microlenses or other optical features provided by localised regions of graded refractive index variation and/or localised contour variations, of a mean size small in relation to the mean size of said areas, said second areas being substantially free of such microlenses or like optical features or having thereover one or more microlenses or other optical features of a mean size substantially greater than said mean size of the microlenses or other optical features in said first areas, or said second areas otherwise having light transmitting or modifying characteristics substantially different from said first areas, and wherein said microlenses or other optical features of at least said first areas have been produced by exposure of the corresponding monomer to a polymerising light pattern.
3. A product according to Claim 1, wherein said second areas comprise an array of similar transparent regions in

a translucent light diffusing field formed by said first areas.

4. A product according to Claim 2, wherein said transparent regions are arranged in a quasi-regular two-dimensional array in which each said transparent region has a respective random displacement from a nominal position thereof in a respective notional regular array of such nominal positions, each said displacement being small in relation to the size of each said transparent region.

5. A product according to claim 1 wherein said second optical features comprise localised contour variations which are non-coincident with said second optical features.

6. A product according to claim 5 wherein said sheet or layer of photopolymer incorporates an array of graded refractive index microlenses and has at least one major surface thereof embossed or otherwise surface-contoured so as to form a plurality of curved surfaces each forming a surface-refraction lens and wherein a plurality of said graded refractive index lenses lies within the area of each such surface refraction lens.

7. A photo-electric sensor or solar cell comprising a plate of semi-conductor material and, extending over the surface of said plate to be exposed to light, a microlens screen formed of photopolymer material, said microlens screen comprising a plurality of microlenses each arranged to focus incident light onto a respective spot on said plate.

8. A microlens screen formed of photopolymer material and wherein the interstices between adjoining microlenses are rendered opaque by pigment adhered to the photopolymer.

9. A microlens screen comprising a layer of photopolymer incorporating the microlenses, adhered to an opaque plastics film formed with apertures in regions corresponding to said microlenses incorporated in the photopolymer layer, whereby the opaque film will prevent light passing through the photopolymer layer except through the microlenses.

10. A microlens screen comprising a sheet or layer of photopolymer incorporating a plurality of microlenses or other optical features, the sheet or layer having, or conforming to a curved surface, such as a part-spherical surface of a surface otherwise curved simultaneously in more than one direction.

11. A method of forming a microlens screen by exposing a sheet or layer of a photopolymerisable material to polymerising light through a mask having a plurality of light transmitting apertures in an opaque field, or a plurality of opaque spots in a light-transmitting field, and wherein each said aperture or spot has its margin at regions formed as a neutral density filter of precisely determined variation in density with distance from the fully opaque region of such opaque field or of such opaque spot.

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Fig.1.

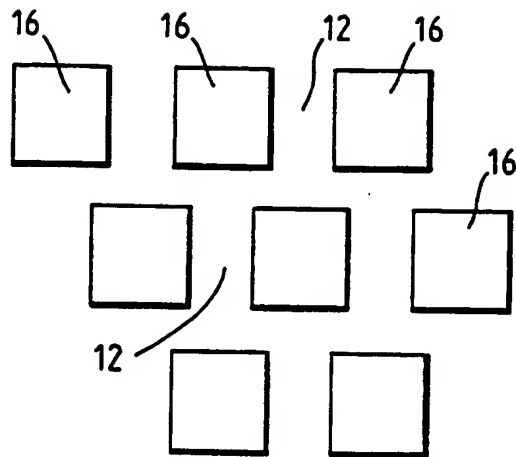


Fig.2.

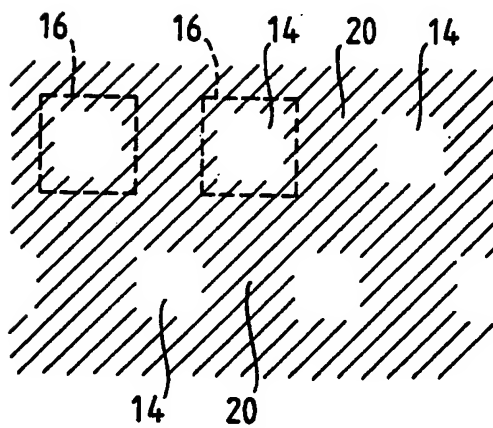
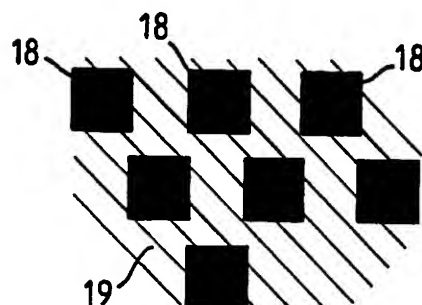


Fig.3.



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Fig.4.

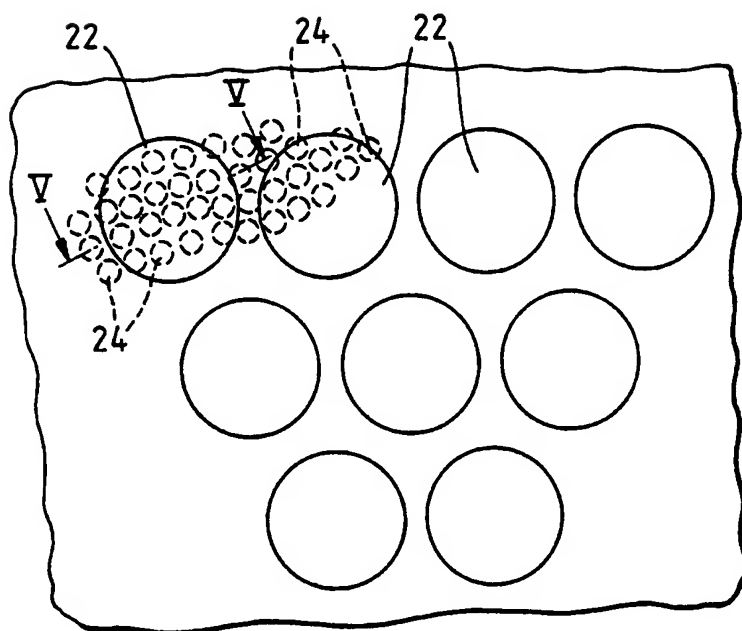
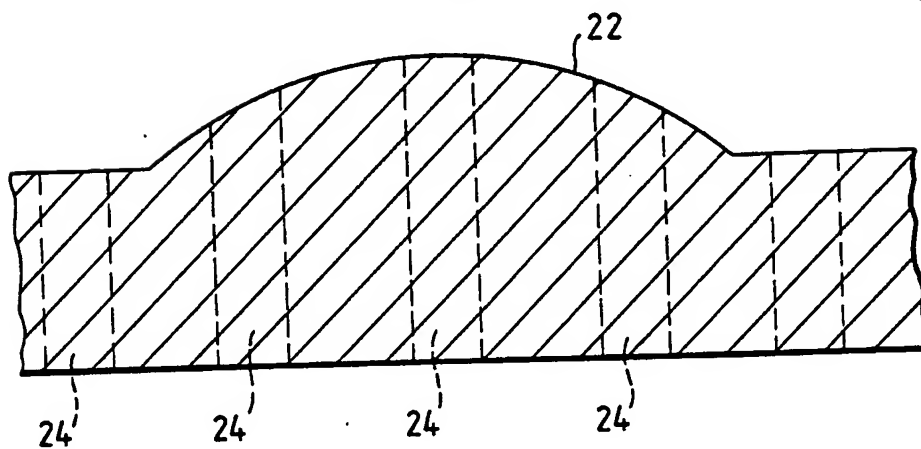


Fig.5.





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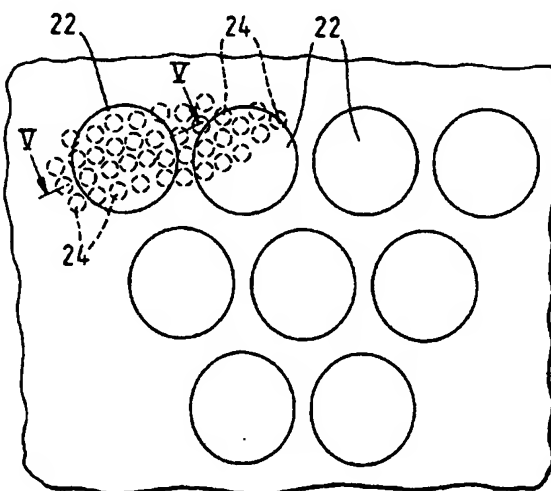
With international search report.

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(57) Abstract

Various combinations of different optical features in a microlens screen are disclosed. In one arrangement, a screen is provided for depixelating purposes, comprising an array of transparent rectangular portions (14) in a light diffusing field (20) formed by minute closely packed microlenses of the graded refractive index type. In another arrangement, a screen formed with an array of integral graded refractive index lenses has surface refractive index lenses additionally provided by part-spherical embossments on a surface of the screen, the embossments being of one or more orders of magnitude greater in diameter than the graded refractive index lenses. There are also disclosed techniques for preventing light transmission through a microlens screen except through the microlenses, the use of microlens screens to improve the performance of solar panels and microlens screens conforming to a part-spherical surface.

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INTERNATIONAL SEARCH REPORT

Intern: al Application No
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IPC 6 G02B3/00 G03B21/62

According to International Patent Classification (IPC) or to both national classification and IPC:

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G02B G03B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US,A,5 074 649 (NIPPON SHEET GLASS CO., LTD.) 24 December 1991 see column 2, line 38 - line 65; figures 1,2A,2B ---	1-6
X	WO,A,88 09952 (SCIENTIFIC APPLIED RESEARCH PLC) 15 December 1988 cited in the application see page 8, line 10 - page 9, line 19; figures 1,2 ---	1-6
A	PATENT ABSTRACTS OF JAPAN vol. 10, no. 22 (P-424) (2079) 28 January 1986 & JP,A,60 175 001 (TOSHIBA K.K.) 9 September 1985 see abstract --- -/--	1-6

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

21 December 1994

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03.03.95

Name and mailing address of the ISA

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INTERNATIONAL SEARCH REPORT

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>Conference on lasers and electro-optics 1991 May 12-17, 1991, Baltimore, Maryland, USA CMD2, pages 30-31, T. Maeda et al.: "Photopolymerized micro Fresnel lens array" see abstract</p> <p>-----</p>	1-6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/GB94/01899

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. CLAIMS 1-6
2. CLAIM 7
3. CLAIMS 8-9
4. CLAIM 10
5. CLAIM 11

For further information please see form
PCT/ISA/206 mailed 30.12.94

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
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1-6

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- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/GB 94/01899

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A-5074649	24-12-91	JP-A- 3055501 US-A- 5130852	11-03-91 14-07-92
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